Investigation on Wire EDM Input Parameters for Optimizing Material Removal Rate and Surface Roughness (on Aluminium Alloy Grade AA7075)

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Abstract— In the present work an attempt is been made to optimize the performance parameters of wire-cut electric discharge machining on AA7075 aluminium alloy, this can be achieved by adjusting the input parameters for optimizing material removal rate and surface roughness. The process parameters considered are Spark on time, Spark off Time, Pulse Current and Gap voltage. The working ranges and levels of the Wire Cut EDM process parameters are found using Fractional Factorial Design. The data obtained from the above experiment is utilized to deduce optimum input parameters for best machining performance based on grey relational analysis.

Key words: WIRE EDM, AA7075 Aluminium Alloy, Surface Roughness, Fractional Factorial Method, Grey Relational Analysis (GRA)

I. Introduction

Electric Discharge machining is an unconventional process where-in the thermal energy generated by ionization of dielectric medium is used to melt and remove metal, this phenomenon is known as electrode erosion effect. It used for machining of hard materials which can't be machined by conventional machining processes. Material removal rate and surface finish are the general measures of performance for any metal removal processes. With good EDM Machining equipment it is possible to cut small odd-shaped angles, detailed contours or cavities in hardened steel as well as exotic metals like titanium, hastelloy, inconel, and carbide. Electric discharge machining is one among such process wherein thermal energy generated during electric spark in dielectric medium is used to cut the metal. There are two kinds of Electric discharge machine (EDM), and wire-cut EDM or WEDM is one of among those, it is generally used to cut intricate shapes on metals, in making dies and several other applications

II. Past Work in the Field of WEDM

Enormous amount of work has been reported ever since the process is established and the numerous researches carried out on Wire- EDM

Vikas [1] etal. (2014) carried out the optimization of the Material removal rate for EN41 and EN19 based on the 4 input parameters namely the pulse on time, pulse off time, discharge current and gap voltage. He found out that the discharger current had a larger impact over the Material removal rate followed by some of the interaction plot, while the effect of the other parameters were minor.Not only for alloy steels, many researches were done on several other materials, say for instance B.H Yan [2] etal. studied the effect of multiple characteristics of WEDM on composite materials and found that abrasive reinforcements present in composite matrix effect machinability.

B. Bhattacharyya[3] etal. (2003) has investigated variation of geometric inaccuracy due to wirelag against parametric settings and optimised using taguchi method. Zahid [4] etal. (2014) and Mahdavinejad [5] etal. (2009) have worked with grey analysis and controller model respectively on WEDM parameters using Taguchi methodology. K. L. Meena[6]etal. (2013) have studied the effect of wire feed rate and wire tension during machining of Pr-Al-SiC- material composite by wire-EDM and found optimal setting for it From the extensive literature review done it seems that contribution done in the area of optimising non-electrical process variables to obtain better material removal rate and surface was very limited, hence this form the basis of the current paperwork.

III. Experimental Setup

A. *Material*

The material chosen for study AA7075 Aluminim Alloy. It is alloy with content of aluminium 87.9-91.4 , zinc 5.1-6.1 along with other minor alloying elements like Manganese 0.3, Silicon 0.4, Iron 0.5 and Titanium 0.2 . Possessing high Brinells hardness and ultimate tensile strength it best machined on WEDM, it is widely used in making dies, aircraft manufacturing and components which are subjected to high loads. Cast aluminium alloys yield cost-effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Aluminium Alloys being used in industries as diverse as transport, food preparation, energy generation, packaging, architecture, and electrical transmission applications.

B. *Experimental Parameters*

Based on the Machine used for WEDM process and the mechanical properties of the material used in the present study, input variables are chosen.

Table-1 shows the control parameters and input settings used in the experiment

Control Parameters	Units	Symbol	Levels	
			Low	High
Spark On Time	µs	A	105	110
Spark Off Time	µs	B	50	60
Pulse Current	Amps	C	10	12
Gap Voltage	V	D	50	90

Table 1: Control parameters and their settings

Utilizing fractional factorial method, eight experiments were designed and conduction the material and input setting for each experiment is shown the table-2.

Run Order	Spark On Time	Spark Off Time	Pulse Current	Gap Voltage
1	high	high	high	high
2	high	high	low	low
3	low	low	high	high
4	low	low	low	low
5	low	high	low	high
6	low	high	high	low
7	high	low	low	high
8	high	low	high	low

Table 2.1: Experimental inputs based on fractional factorial method

Run Order	Spark On Time	Spark Off Time	Pulse Current	Gap Voltage
1	110	60	12	90
2	110	60	10	50
3	105	50	12	90
4	105	50	10	50
5	105	60	10	50
6	105	60	12	50
7	110	50	10	90
8	110	50	12	50

Table 2.2**:** Experimental inputs based on fractional factorial method

C. Experiment Process

Firstly the work-piece is sent for milling to remove taperedness. This gives the agility for easy setting up of work-piece on the worktable. An electrolytic brass wire with a diameter of 0.25mm has been used as a tool electrode (positive polarity) and work piece materials used is AA7075Aluminium Alloy of rectangular plates with dimensions 150 x 80 x10 mm. De-ionised water is used as dielectric fluid with transverse flushing.

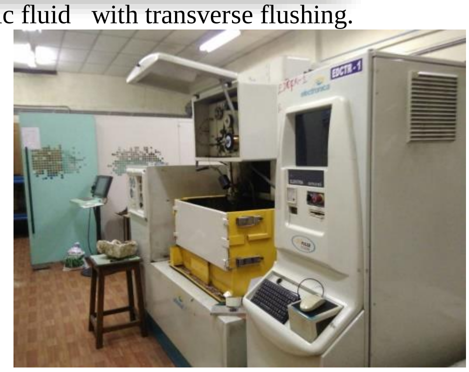

Fig. 2(a): Electronica Ultracut S2 Wire-EDM

Fig. 2(b): AA7075Alloy during wire EDM process

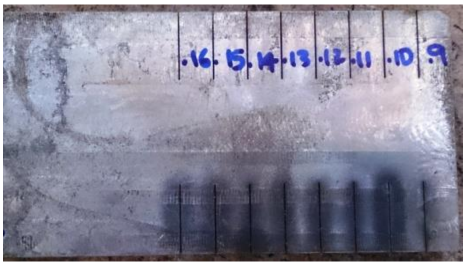

Fig. 2(c): Workpiece after 16 experiment are made

Fig. 2(d): Test-pieces who surface Roughness is measured

To reduce variability and reliability experimental results, the experiments are replicated twice. The mean of responses obtained from the replications are considered. After running the trails we obtain work-piece as shown in the figure 2(c). Now the material removal rate is measured as the volume of material removed in the machining time. So for determining the volume of material removed, the slot cut by the WEDM is measured on vertical profile projector at 20X magnification then value obtained is multiplied with thickness and length of cut to determine the volume of material removed. And “Taylor Hobson-Subtronic 3+” Surface tester is used to get the average surface roughness of the each test piece figure 2(d).which is separated from the work-piece shown in figure 2(c) by milling operation. The responses obtained from the experiments are enumerated in table 3.

Trail No.	Cut Width (cm)	Thick-ness (cm)	Cut length (cm)	Time (mins)	MRR (mm^3/min)	Surface roughness (µm)
1	0.02	9.94	2	9	44.0177	1.73
2	0.03	9.94	2	15	39.76	1.56
3	0.02	9.94	2	11	36.145	2.08
4	0.02	9.94	2	24	16.56	1.64
5	0.025	9.94	2	72	6.902	1.69
6	0.025	9.94	2	7	71	2.35
7	0.02	9.94	2	31	12.825	1.45
8	0.02	9.94	2	10	39.76	1.51

Table 3: Responses obtained from the experiments

IV. Grey Relation Analysis

Grey relational analysis is a part of Grey theory proposed by Professor J.L Deng [7]. GRA is a multivariate optimization techniques where in grades are calculated for the terms in the sequence and later there characteristics are determined based on the grey theory principles. It mainly consists of three steps which will be discussed in further sub sections.

A. Data Preprocessing

The raw data obtained from the experimentation is normalized using the equations (1) and (2). If the target value of original sequence is infinite, then it has a characteristic of "the larger-the –better". The original sequence can be normalized as follows.

$$x_i^*(k) = \frac{x_i^0(K) - \min x_i^0(K)}{\max x_i^0(K) - \min x_i^0(K)} \quad (1)$$

If the expectancy is the smaller-the better, then the original sequence should be normalized as follows.

$$x_i^*(k) = \frac{\max x_i^0(K) - x_i^0(K)}{\max x_i^0(K) - \min x_i^0(K)} \quad (2)$$

For best performance of any machining process we require higher MRR and lower surface roughness, so we use the equation (1) for MRR and equation (2) for surface roughness. Values obtained from calculations are table 4

Trail Number	MRR (mm^3/min)	Surface roughness (μm)
Ref. sequence	1.0000	1.0000
1	0.5815	0.6888
2	0.5126	0.8777
3	0.4562	0.3
4	0.1507	0.7888
5	0	0.7333
6	1	0
7	0.0924	1
8	0.5126	0.9333

Table 4: The sequences of each performance characteristic after data processing

B. *Grey Relational Coefficient*

Following data pre-processing, a grey relational coefficient is calculated to express the relationship between the ideal and actual normalized experimental results. They grey relational coefficient can be expressed as follows

$$\zeta_i(k) = \frac{\Delta_{min} + \zeta.\Delta_{max}}{\Delta_{oi}(k) + \zeta.\Delta_{max}}$$

Where $\Delta_{oi}(k)$ is the deviation sequence of the reference $x_o^*(k)$ and the comparability sequence $x_i^*(k)$, derived as

$$\Delta_{oi}(k) = ||x_o^*(k) - x_i^*(k)||$$

$$\Delta_{max} = max_{\forall j \in i} max_{\forall k} ||x_o^*(k) - x_i^*(k)||$$

$$\Delta_{min} = min_{\forall j \in i} min_{\forall k} ||x_o^*(k) - x_i^*(k)||$$

ζ is distinguishing or identification coefficient ζ ∈ 0,1 . ζ = 0.5 is used when extent of influence of subjects in analysis is not known properly. Calculations are performed for i=1 to 8 and the results of all for i=1 to 8 are presented in Table 5.

Deviation Sequences	∆oi(1)	∆oi(2)
Exp. No. 1	0.4184	0.3111
Exp. No. 2	0.4873	0.1222
Exp. No. 3	0.5437	0.7
Exp. No. 4	0.8492	0.2111
Exp. No. 5	1	0.2666
Exp. No. 6	0	1
Exp. No. 7	0.9075	0
Exp. No. 8	0.4873	0.0666

Table 5: Table showing deviation from reference sequence

C. *Grey Relational Grade*

After obtaining the grey relational coefficient, we normally take the average of the grey relational coefficient as the grey grade. The grey relational grade is defined as follows.

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \zeta_i(k)$$

Trail	Grey relational coefficient		Grey Relational grade
	Grey coef for MRR	Grey coef for Ra	
1	0.5443	0.6164	0.5804
2	0.5063	0.8035	0.6549
3	0.4790	0.4166	0.4478
4	0.3705	0.7031	0.5368
5	0.3333	0.6521	0.4927
6	1	0.3333	0.6666
7	0.3552	1	0.6776
8	0.5063	0.8823	0.6943

Table 6: The calculated grey relational coefficients and grey relational grade

V. RESULTS AND DISCUSSION

According to Grey Relational Analysis, higher grey relational grade represents that the corresponding experimental result is closer to the ideally normalized values. Trail 8 has the higher Grey relational grade which implies it has strong correlation with the ideal/reference sequence; hence it is the optimal setting from the set of experiments performed. So, optimal setting is A(High)B(Low)C(High)D(Low). A graph is drawn between grey relational grade against trail number to demonstrate the variation and for identifying the highest Grey relational grade.

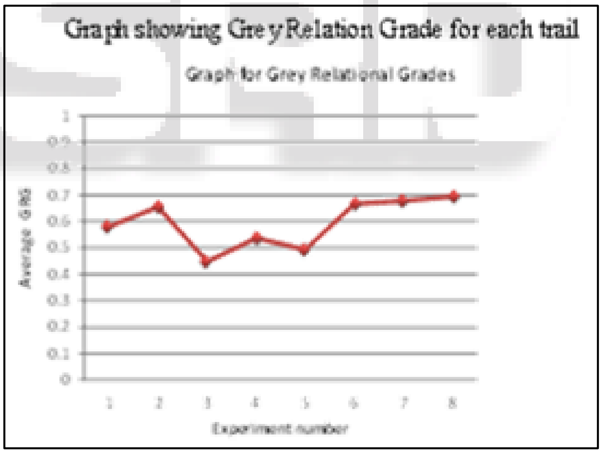

Fig. 3: Graphs showing GRG vs. Experiment Number

A. *Influence of each Factor*

Since the experimental design is fractional factorial, it is then possible to separate out the effect of each machining parameter on the grey relational grade at different levels. Table 5 show the average of grey relational grade at each level and the asterisk mark above them shows that they possess dominant role in experiment, so they are used in confirmation test to validate the experiment.

Symbol	Machining Parameters	Grey Relational Grade		Main Effect	Rank
		Low	High		
A	Spark On Time	0.5360	0.6518 *	0.1158	1
B	SparkOff Time	0.5891	0.5987 *	0.0095	3

C	Pulse Current	0.5905	0.5973 *	0.0067	4
D	Gap Voltage	* 0.6382	0.5496	0.0885	2
Total mean value of grey relational grade γ_m = 0.593937					

Table 7: Grey Relation Grade for each WEDM parameter

A graph is drawn between average GRG values of each factor at low and high levels and its deviation is measured against the mean of total mean grade value. This can be seen in figure 4, the blue line shows the total mean of grey relational grade for whole process and the red line indicates the variation of each factor with change in their level.

It is found the spark on time has major influence on the machining process as it shows larger deviation for given change in the level. It is also observed that pulse current doesn't have much influence on machining process in chosen level as it doesn't intercept the total mean of the process. This is again restated in table 7 by the means of "main effect column", the column with highest deviation is known to have major influence.

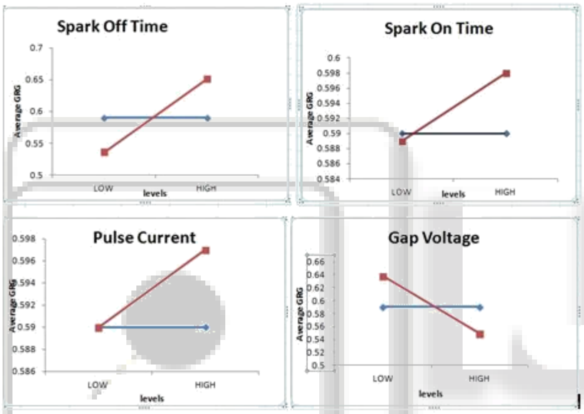

Fig. 4: Graph showing Average Grey Relation grade for each factor

B. Confirmation Test

After identifying the most influential parameters, the final phase is to verify the surface roughness and the cut width by conducting the confirmation experiments. The test settings are selected via the grey relational analysis table 5which shows the levels with dominant effect. Therefore, the condition A(High)B(High)C(High)D(Low) forms the parameter combination during WEDM. The result of the confirmation test gives the surface roughness average and the MRR as 1.56µm and 55.2mm3/min respectively. This shows and improvement of 15.6% in MRR and 0.05% in Surface roughness.

VI. CONCLUSION

In this study, Fractional factorial method with grey relational analysis has been used to optimize material removal rate and surface roughness. It is found that pulse on time is most significant factor among the chosen process variables in WEDM process. Confirmation test shown an improvement of 15.6% and 0.05% improvement in MRR and surface roughness.

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